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HIGH-VELOCITY WATER JET IMPACT ON CONCRETE SAMPLES

Abstract:

The concrete samples with various erosion states were disintegrated inside the overpressure vessel using high-velocity water jet and depth of penetration was measured. Removing of the eroded parts of samples was also tested using low-pressure generated continuous or pulsing fan jets and rotating jets. The influence of the erosion states, water jet techniques, traverse rate and stand-off distance on the disintegration volume was studied and the surface topography was investigated. The high-pressure generated continuous water jet was applied in the overpressure vessel used for simulation of pressures equivalent to the submersion to several depths under the water level. The low-pressure generated continuous or pulsing jets were applied in air conditions. Some samples of special decorative concretes were also studied.

Keywords:

water jet, concrete, depth of penetration, disintegration volume

INTRODUCTION

The first serious approach to water jet use for concrete cutting was probably performed by McCurrich and Browne (1972). The water-jet techniques are widely used for cleaning, profiling, removal, drilling and demolition of concrete substrates (Momber, 1998). Research presented in this paper is aimed at the influence of the erosion states, water jet techniques, traverse rate and stand-off distance on the disintegration volume. The depth of penetration of the submerged water jets into the concrete samples was also measured. The samples were prepared in special laboratories of the Faculty of Civil Engineering of the Technical University in Brno and they are used for simulation of chemical plants, sewages, aggressive underground waters and many more corrosive media. Except the most common concretes used for constructions some special samples of decorative concretes were tested.

DESCRIPTION OF EXPERIMENTAL MATERIAL

The experimental blocks were prepared from several types of the high-strength concrete characterized by the cement type CEM I 42.5; the water coefficient 0.4. The gravel aggregate was Moravian wacke from locality Bohučovice with fractions 0-16 mm. The average specific density of the concrete is 2750 kg·m^{-3} and the average uniaxial compression strength is 62.8 MPa. These samples are referred as "Concrete type III".

Other blocks were prepared as a standard concrete sort B30 (according to the Czech *norms); the stone fraction 0-4 mm is from the locality Ledce, the stone fraction 8-16 mm is from the locality Olbramovice, the stone fraction 11-22 mm is from the locality Lomnička and the plasticizer Sikament 100 is used. All stone localities are in the Czech Republic. These samples are referred to as "Concrete type II". They were separated into several groups. The first one was the reference group stored in common indoor air conditions. The second group of samples was stored in the lotion with a high concentration of the NH^{3-} ionts (up to 4%) simulating aggressive media in chemical industry or in sewage canals and other structures. The third group of samples was stored in the lotion with the Na_2SO_4 (concentration of the Na_2SO_4 is 51.2 grams per liter of water) simulating thus media in aggressive setting (chemical and sewerage plants, groundwater rich in concentration of sulphates). The fourth group of samples was stored in a special container with a high concentration of the CO_2 gas and the relative humidity 90% - these conditions simulate the process of concrete carbonation in air due to the CO_2 influence in combination with the air humidity or they simulate activity of the aggressive CO_2 from the groundwater. The fifth group of samples was stored in the solution of the NaCl in water (100 grams per liter) simulating aggressive media in the sewerage plants, in the water treatment plants or in the pools with the chlorinated water. The sixth group of samples was exposed by several tenths of freezing and de-freezing cycles. The lotions were changed each two months and their pH factors were tested each fourteen days.*

The concrete samples referred as "Concrete type I" were prepared from concrete used for outdoor medium loaded planes built before 1989. The exact structure is not known but it is a concrete with rather small size stones.

Some samples were prepared in the Research Institute of Building Materials, Inc., Brno, Czech Republic. These concretes (BP1, BP2, BP3) were prepared using fine sands, instead of the usual gravel aggregate, some pigments and special fabrics acting like the reinforcement (silicon fibers in one plane or silicon based tissue). They are used specially as the decorative concretes inside and outside the industrial buildings.

EXPERIMENTAL PROCEDURE

Concrete samples were tested in the overpressure vessel produced several years ago (Hlaváč et al., 2001). The samples were approximately 150 x 100 x 50 mm. In the beginning of each experiment the respective block was fixed into the support of the motional device inside the pressure vessel (Fig. 1). The vessel was closed and filled with water except the case when the tests were performed in air for comparison. Water inside the vessel was either without any pressure or pressurized. The overpressures were set from zero up to 1.4 MPa with the 0.2 MPa step.

Fig. 1. Support with sample in front of the pressure vessel

Pressurizing of the water inside the chamber was supplied by the inflow from the cutting nozzle and by the regulation overflow valve. The water pressure inside the vessel was measured using the mechanical pressure meter installed at the vessel body. The kerfs were performed at various traverse rates. Pump pressure was 380 MPa, the nozzle diameter was 0.25 mm, the stand-off distance was 10 mm (from the nozzle outlet) and the angle between the jet axis and the normal to the impingement surface of the samples was 0 rad. The depths of kerfs were measured in five points assigned on the respective sample surfaces and the average values of the depth of all kerfs were evaluated. The experimental results were then fitted by means of polynomial regression. The A_k coefficient was selected as the criterion for the optimal order of the polynomial (Anděl, 1998).

The multivariate analysis of variance (MANOVA) was used to judge whether changes in factors like erosion state, water jet technique, traverse rate and stand-off distance have the significant effects on the disintegration volume.

Simultaneously, some experiments with the low-pressure based water jets were performed either with nozzles Lechler 1508 having the outlet diameter 2.05 mm and producing fan jets with vertex angle 30° or with the rotating head Barracuda carrying two nozzles with outlet diameter 1.19 mm. The nozzle inlet diameter was 4 mm in both cases. Water pressure was 30 MPa, the stand-off distance was 20, 40 or 50 mm and the amplitude of vibrations was 7 μm if applied. The experiments were performed with traverse rates 100, 200, 400 and 1000 mm per minute. The disintegrated volume was determined for the length 150 mm that corresponds to the dimension of the sample. Typical width of the fan jet trace on the material surface was 22 mm, and about 30 mm for head Barracuda. The depth of penetration altered from about 1 mm without pulsing up to more than 10 mm with pulsing switched on.

RESULTS AND DISCUSSION

The results obtained on the construction concretes without any additional treatment are presented in Fig. 2. The results obtained on the construction concrete samples remitted to the influence of various aggressive media are shown in Fig. 3. The cutting results from tests performed on decorative concretes are summarized in Fig. 4. Some of the results are the anticipated ones. The decrease of the depth of penetration with increasing overpressure inside the vessel is one of the most expected ones. The reduction of the penetration efficiency was expected also for concretes with the large-size stones. This presumption was confirmed partially (Fig. 2) but not fully. The large volume disintegration occurred (Fig. 3) and so the measurement of the depth of penetration of water jet into the concrete sample was made very difficult. It is evident, that measurement of the depth of penetration should be modified or replaced by another characteristic parameter, e.g. disintegrated volume.

The decorative concretes are rather cut than volume disintegrated. Therefore, the rapid decrease of the depth of penetration (Fig. 4) measured for increasing overpressure inside the vessel can be hardly influenced by some large breaks on the sample surface. So, the dominant role seems to be played by the fibrous base. The fibers were prepared as planes from various materials and their positions inside the concretes were varying. The elasticity of such fibrous base and its non-homogeneity can explain behavior of the samples from the decorative concretes satisfactorily.

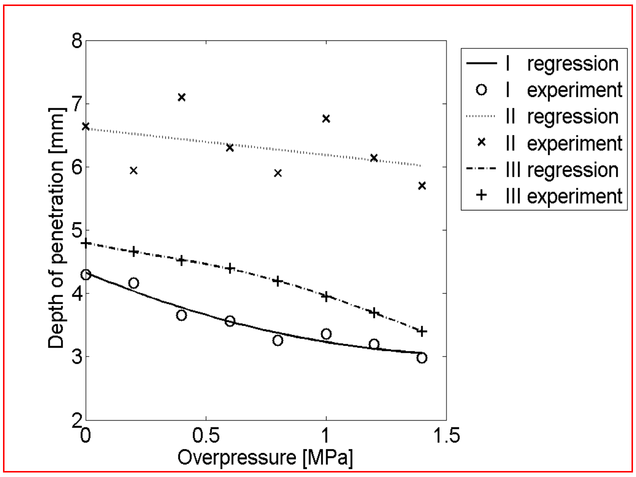

Fig. 2. Effect of overpressure in the vessel on depth of penetration for construction concretes without any additional treatment (I, II and III – types of the concrete); The orders of the polynomial fitting are: I – 2, II – 1, III – 4

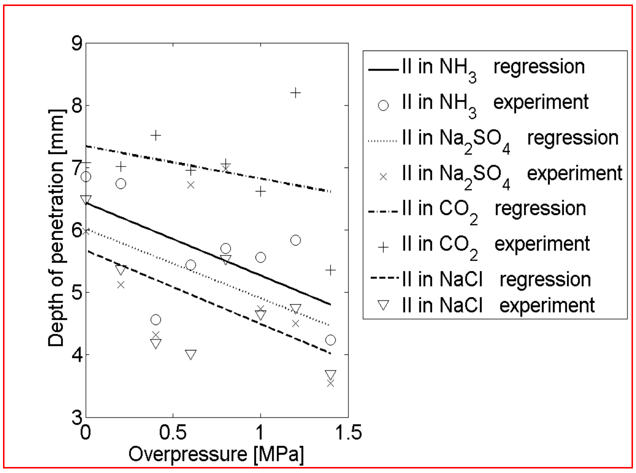

Fig. 3. Effect of overpressure in the vessel on depth of penetration for samples prepared from concrete II and submitted to various chemical influences. The order of the polynomial fitting is 1

The significant effect of the traverse rate, water jet technique and erosion state on the disintegration volume was demonstrated by means of the F-test value on the significance level α = 0.05 (Tab. 1). Experimental data set applied is presented in Tab. 2.

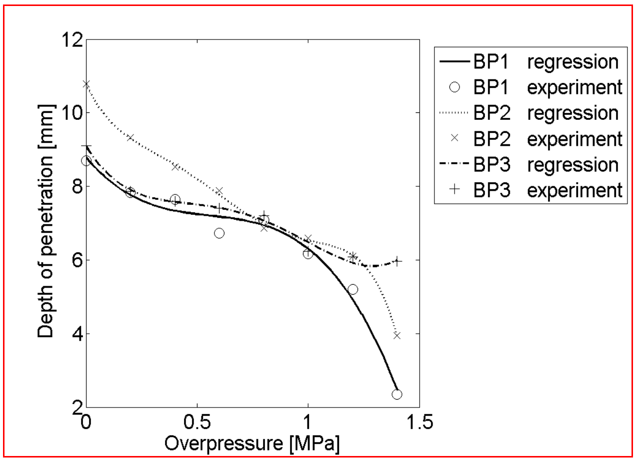

Fig. 4. Effect of overpressure in the vessel on depth of penetration for construction decorative concretes. The orders of the polynomial fitting are: BP1 – 3, II – 5, III – 4

Multivariate analysis of variance is performed for disintegrated volume of samples presented in Tab. 1. Source term is the source of variation in the model. The abbreviation DF means the degrees of freedom, i.e. the number of observations corresponding to this term. The sum of squares represents the sum of squares for this term and the mean square is the sum of squares divided by the degrees of freedom. The label F-ratio means the F-test value, while prob. level is the significance level of the F-ratio. Power (α = 0.05) means the probability of rejecting the hypothesis that the means of the disintegrated volume in different groups are equal when they are in fact not equal. Photo of some samples of construction concretes is presented in Fig. 5. It demonstrates variation in the water jet effects with increasing depth of submersion.

Fig. 5 Selected samples of construction concretes

Tab. 1. Analysis of variance table for disintegrated volume

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob. Level	Power (α= 0.05)
Sample	6	4614.796	769.132	4.90	0.0003*	0.9869
Techniques	3	2625.653	875.217	5.57	0.0017*	0.9312
Rate	3	3860.037	1286.67	8.19	0.00009*	0.9892
Distance	2	6.43051	3.21525	0.02	0.97973	0.0529
Nozzle diameter	1	0	0	0	1	0.05
S	71	11149.4	157.034			
Total (Adjusted)	86	26107.7				
Total	87					

* Term significant at α = 0.05

Tab. 2. Analyzed concretes (RCH: reference CH, C: CHRL 100, F: freeze 100, NaCl: chloride, SO4: sulfate, R: reference, N: NH3)

Sample	Water-jet Technique	Traverse Rate (mm/min)	Stand-off Distance (mm)	Nozzle Diameter (mm)	Disintegrated Volume (cm^3)
RCH	FP	200	40	2.05	24.0
RCH	FC	200	40	2.05	6.0
C	FC	200	40	2.05	22.0

Tab. 2. Analyzed concretes (RCH: reference CH, C: CHRL 100, F: freeze 100, NaCl: chloride, SO4: sulfate, R: reference, N: NH3) [continuing]

Sample	Water-jet Technique	Traverse Rate (mm/min)	Stand-off Distance (mm)]	Nozzle Diameter (mm)	Disintegrated Volume (cm^3)
RCH	FP	400	40	2.05	21.0
RCH	FC	400	40	2.05	6.0
C	FP	400	40	2.05	30.0
C	FC	400	40	2.05	26.3
C	FP	200	40	2.05	31.7
RCH	FP	100	40	2.05	29.3
RCH	FC	100	40	2.05	9.8
C	FP	100	40	2.05	28.3
C	FC	100	40	2.05	22.5
C	RP	400	50	1.19	50.0
C	RC	400	20	1.19	23.6
RCH	RP	400	50	1.19	22.0
RCH	RC	400	20	1.19	7.0
RCH	FP	1000	40	2.05	15.0
RCH	FC	1000	40	2.05	2.3
C	FP	1000	40	2.05	21.0
C	FC	1000	40	2.05	7.5
C	RP	1000	50	1.19	39.4
C	RC	1000	20	1.19	24.4
RCH	RP	1000	50	1.19	17.5
RCH	RC	1000	20	1.19	6.3
RCH	RP	100	50	1.19	48.8
RCH	RC	100	20	1.19	8.8
RCH	RP	200	50	1.19	23.8
RCH	RC	200	20	1.19	3.7
F	FC	400	40	2.05	60.0
F	FP	400	40	2.05	112.5
F	RP	400	50	1.19	27.3
F	RC	400	20	1.19	13.5
F	RP	1000	50	1.19	18.8
F	RC	1000	20	1.19	6.8
F	RP	200	50	1.19	46.0
F	RC	200	20	1.19	23.7
F	RP	100	50	1.19	49.0
F	RC	100	20	1.19	43.5
NaCl	FP	400	40	2.05	22.5
NaCl	FC	400	40	2.05	6.8
NaCl	FP	100	40	2.05	27.0
NaCl	FC	100	40	2.05	9.0
NaCl	FP	200	40	2.05	24.0
NaCl	FC	200	40	2.05	8.3
NaCl	FP	1000	40	2.05	19.5
NaCl	FC	1000	40	2.05	5.0
SO4	FP	400	40	2.05	17.8
SO4	FC	400	40	2.05	5.0
SO4	FP	100	40	2.05	33.0
SO4	FC	100	40	2.05	12.0
SO4	FP	200	40	2.05	21.0
SO4	FC	200	40	2.05	6.0
SO4	FP	1000	40	2.05	13.5
SO4	FC	1000	40	2.05	3.0
R	RP	400	50	1.19	35.0
R	RC	400	20	1.19	18.8
R	RP	1000	50	1.19	20.0
R	RC	1000	20	1.19	10.0
R	RP	100	50	1.19	47.5
R	RC	100	20	1.19	41.3
R	RP	200	50	1.19	42.5
R	RC	200	20	1.19	17.5
NaCl	RP	400	50	1.19	41.3
NaCl	RC	400	20	1.19	11.3
NaCl	RP	1000	50	1.19	10.0
NaCl	RC	1000	20	1.19	6.3
NaCl	RP	100	50	1.19	50.0
NaCl	RC	100	20	1.19	36.3
NaCl	RP	200	50	1.19	55.0
NaCl	RC	200	20	1.19	35.0
SO4	RP	400	50	1.19	21.3
SO4	RC	400	20	1.19	7.5
SO4	RP	1000	50	1.19	16.3
SO4	RC	1000	20	1.19	4.4
SO4	RP	100	50	1.19	41.3
SO4	RC	100	20	1.19	13.8
SO4	RP	200	50	1.19	30.0
SO4	RC	200	20	1.19	15.0
N	RP	400	50	1.19	23.8
N	RC	400	20	1.19	20.0
N	RP	1000	50	1.19	30.0
N	RC	1000	20	1.19	11.3
N	RP	400	20	1.19	40.0
N	RP	100	50	1.19	53.8
N	RC	100	20	1.19	45.0
N	RP	200	50	1.19	30.0
N	RC	200	20	1.19	11.3

CONCLUSION

The disintegration decreases with the depth of submersion and that water jets in deeper submersion act like the ones generated from lower pressure in the air medium. The influence of the concrete aging in special solutions on the cutting ability of the submerged water jet was not proved. The disintegrated volume can be applied for estimation of water jet efficiency.

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